Exceptional Point Induced Robust Unidirectional Guided Resonance in Perturbed Silicon Nanogratings

We investigate the relation between UGRs and EPs in perturbed silicon nanogratings and show that the region delimited by the EP helps maintain the UGR destructive interference condition under parameter perturbations.

J. Ding[1], Y. Zheng[2], M. Luo[2], M. Ouyang[1], H, Fan[1], Q. Dai[1], H. Liu[1]*, L. Wu[1] and S. Lan[1]

1. School of Optoelectronic Science and Engineering, South China Normal University, Guangzhou, China.

2. School of Optoelectronic Engineering, Guangdong Polytechnic Normal University, Guangzhou, China.

Abstract

Unidirectional guided resonances (UGRs) enable static unidirectional radiation of eigenstates and have been widely studied. Exceptional points (EPs) in non-Hermitian open systems provide a unique perspective for exploring UGRs. However, existing studies mainly focus on the topological properties of UGRs, while how the region delimited by an EP affects the radiation behavior of UGRs remains unclear. We investigate the radiation of EP related UGRs in a notch perturbed silicon nanograting.

At notch parameters $\boldsymbol{\Delta}$ = 0.3 and $\boldsymbol{\delta}$ = 0.045, the complex eigenfrequencies of two modes coalesce to form an EP. In the region delimited by the EP, a UGR with asymmetric radiation ratio η of 41 dB appears. The radiative losses of the modes remain close in this region, allowing η to remain high under structural perturbations of the grating and variations in the ambient refractive index $\boldsymbol{n_2}$. These results indicate that the region delimited by the EP improves the geometrical tolerance of UGRs.

Methodology

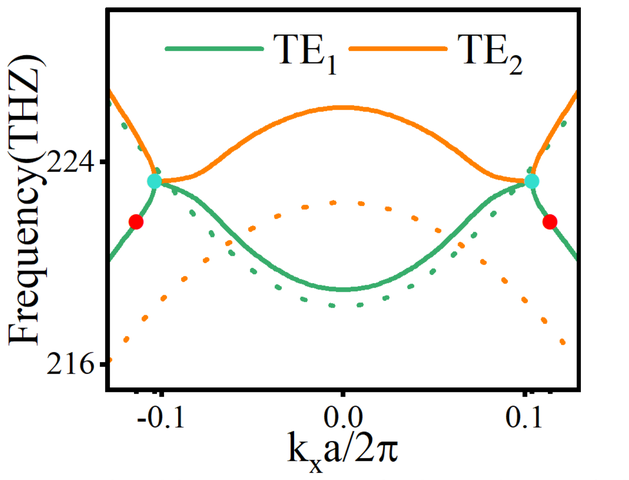


Fig. 1 Dashed lines: uncoupled modes, solid lines: hybridized modes.

The effective Hamiltonian is expressed as:

$$H_{eff} = \begin{pmatrix} \omega_{eig1} & K_{12} \\ K_{21} & \omega_{eig2} \end{pmatrix}$$

The coupled complex eigenfrequencies are obtained as [1,2]:

$$\omega_{eig\pm} = \omega_0 - i\Gamma_0 \pm q.$$

When $q = 0$, the two complex eigenfrequencies and eigenstates coalesce simultaneously, and the EP appears.

The far field radiation amplitudes in the upward and downward radiation channels are written as [3]:

$$s_{\sigma,\pm} = d_{\sigma 1} a_{\pm} + d_{\sigma 2} b_{\pm}, \qquad \sigma = u, d$$

Therefore, the destructive interference condition for a UGR is:

$$d_{\sigma 1} K_{12} + d_{\sigma 2}\left[-\frac{\Delta\omega - i\Delta\Gamma}{2} \pm q\right] = 0.$$

Results

- The results show that UGRs and EPs are not isolated phenomena, but are linked through the same interband coupling process, which regulates both the complex band structure and the radiation channel distribution.
- This comparison indicates that the enhanced tolerance is associated with the band region delimited by the EP. The different responses to Δ and δ are also expected, since these two notch parameters affect the interband coupling strength and the radiation channel coefficients in different ways.

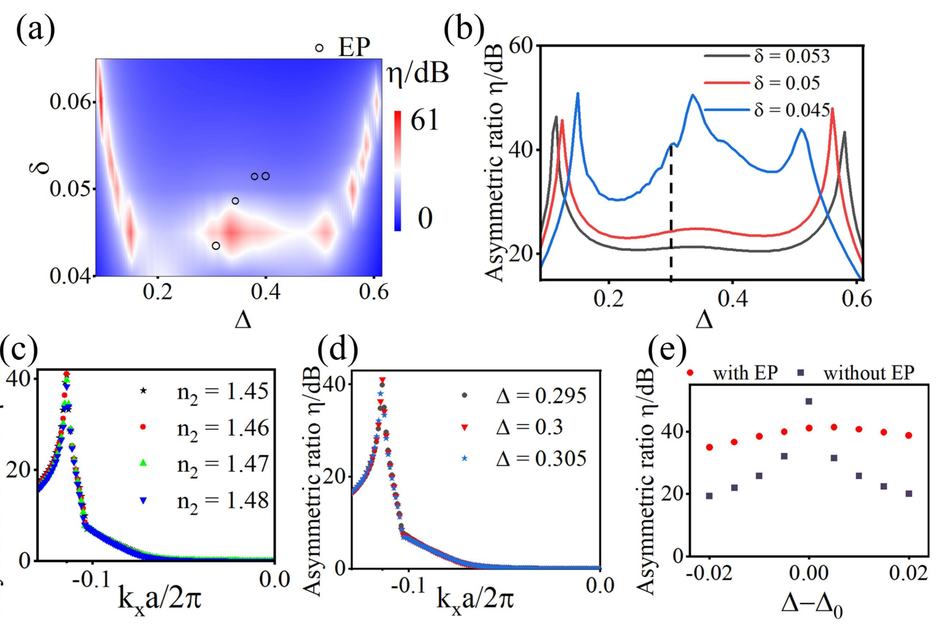


Fig. 2. (a) Distribution of η in the (Δ,δ) parameter space. Circles: EP positions. (b) η versus Δ for three δ values.
(c), (d) η of the UGR coexisting with the EP under variations of n_2 and Δ, respectively.
(e) Comparison between the UGR coexisting with the EP and a regular UGR under Δ detuning.

REFERENCES

[1]. X. Yin, T. Inoue, C. Peng, et al., "Topological unidirectional guided resonances emerged from interband coupling," Phys. Rev. Lett. 130, 056401 (2023).
[2]. S. Fan, W. Suh, and J. D. Joannopoulos, "Temporal coupled-mode theory for the Fano resonance in optical resonators," J. Opt. Soc. Am. A 20, 569 (2003).
[3]. N. D. Le, P. Bouteyre, A. Kheir-Aldine, et al., "Super bound states in the continuum on a photonic flatband: concept, experimental realization, and optical trapping demonstration," Phys. Rev. Lett. 132, 173802 (2024).

SOUTH CHINA NORMAL UNIVERSITY

Excerpt from the Proceedings of the COMSOL Conference 2026 Shenzhen